

Comment on “Limit on the Electron Electric Dipole Moment in Gadolinium-Iron Garnet”

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In [1], a solid-state electron electric dipole moment (EDM) experiment is described in which a sample (GdIG) electric polarization appears when the sample is magnetized. The voltage is induced across a GdIG sample by the alignment of the sample’s magnetic dipole moments (MDMs) in an applied magnetic field \mathbf{H} . All solid-state electron EDM experiments rely on the fact that the electron EDM \mathbf{d} is collinear with its MDM \mathbf{m} , because they are both supposed to be proportional to the spin \mathbf{S} ; it is supposed that \mathbf{S} is the only available 3-vector in the rest frame of the particle. Thus, the interaction of the EDMs and \mathbf{H} is only indirect through the alignment of MDMs, i.e., the three-dimensional (3D) spins, in the field \mathbf{H} .

Recently, [2], the Uhlenbeck-Goudsmit hypothesis is generalized in a Lorentz covariant manner using 4D geometric quantities; the dipole moment tensor D^{ab} is proportional to the spin four-tensor S^{ab} , $D^{ab} = g_S S^{ab}$, Eq. (9) in [2]. The dipole moment vectors d^a and m^a are derived from D^{ab} and the velocity vector of the particle u^a , Eq. (2) in [2]. Similarly, the usual 4D spin S^a , and a new one, the intrinsic angular momentum, spin Z^a , are derived from S^{ab} and u^a , Eq. (8) in [2]. Then, Eq. (10) in [2] is obtained as $m^a = c g_S S^a$, $d^a = g_S Z^a$. Accordingly, the intrinsic MDM m^a is determined by S^a , whereas the intrinsic EDM d^a is determined by the new spin vector Z^a and not, as usual, by the spin \mathbf{S} . Both spins, S^a and Z^a , are equally good physical quantities.

Instead of an indirect interaction between the applied \mathbf{H} and an EDM \mathbf{d} through the alignment of 3D spins by the interaction $-m(\mathbf{S}/S) \cdot \mathbf{B}$, we propose a direct, Lorentz covariant, interaction between B^a and an EDM d^a .

Inserting the decomposition of F^{ab} (in terms of E^a , B^a and the velocity vector v^a of the observers who measure fields), Eq. (1) in [2], and that one of D^{ab} , Eq. (2) in [2], into the interaction term $(1/2)F_{ab}D^{ba}$, one finds Eq. (3) in [2] (it is first reported in [3]). When it is taken that the laboratory frame is the e_0 -frame (the frame in which the observers who measure E^a and B^a are at rest, with the standard basis $\{e_\mu\}$ in it), then $E^0 = B^0 = 0$, and *only* three spatial components E^i and B^i will remain. Similarly, *only* in the particle’s rest frame, with the standard basis in it, $d^0 = m^0 = 0$ and *only* d^i and m^i will remain. Hence, it is not possible that, e.g., in the laboratory frame, *both*, the fields and the dipole moments have *only* three spatial components, i.e., as for the usual 3-vectors. (In all EDM experiments the interaction is described in terms of the 3-vectors as $\mathbf{E} \cdot \mathbf{d}$ and $\mathbf{B} \cdot \mathbf{m}$.)

In the laboratory frame as the e_0 -frame, one can neglect the contributions to L_{int} , Eq. (3) in [2], from the terms with d^0 and m^0 ; they are u^2/c^2 of the usual terms $E_i d^i$ or $B_i m^i$. Then, what remains is

$$L_{int} = -((E_i d^i) + (B_i m^i)) - (1/c^2)\varepsilon^{0ijk}(E_i m_k - c^2 B_i d_k)u_j. \quad (1)$$

With the usual 3-vectors, it would correspond to Eq. (26) in [2]. But, as stated in [2]: “... what is essential for the number of components of a vector field is the number of variables on which that vector field depends, i.e., the dimension of its domain. Thus, strictly speaking, the time-dependent $\mathbf{E}(\mathbf{r}, t)$ and $\mathbf{B}(\mathbf{r}, t)$ cannot be the 3-vectors, since they are defined on the spacetime.” Furthermore, as noticed in [2]: “... neither the direction of \mathbf{d} nor the direction of the spin \mathbf{S} have a well-defined meaning in the 4D spacetime. The only Lorentz-invariant condition on the directions of d^a and S^a in the 4D spacetime is $d^a u_a = S^a u_a = 0$. This condition does not say that \mathbf{d} has to be parallel to the spin \mathbf{S} .” Obviously, the same remark holds if \mathbf{d} is replaced by \mathbf{m} and d^a by m^a . The results from [2] indicate that the basic points of the interpretation of measurements of EDM in [1], i.e., both \mathbf{m} and \mathbf{d} are parallel to \mathbf{S} , are meaningless in the manifestly covariant formulation from [2]. This means that the usual formulation with 3-vectors \mathbf{E} , \mathbf{B} , \mathbf{S} , etc. **IS NOT** relativistically correct formulation.

It is seen from Eq. (1) that the interaction between B^a and a MDM m^a is contained in the term $-B_i m^i$ and that one between B^a and an EDM d^a is contained in the term $\varepsilon^{0ijk} B_i d_k u_j$, which is u^a -dependent.

In conclusion, according to Eq. (1), a voltage induced across the solid is not caused by the alignment of MDMs in an applied field \mathbf{H} than by the polarization of the sample due to the interaction $\varepsilon^{0ijk} B_i d_k u_j$. That voltage can give some information about d^a , because that term contains the EDM d^a .

References

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